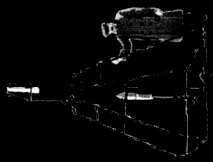




Optical Communications in Support of Science from the Moon, Mars, and Beyond

*Goddard Memorial Symposium
29 March 2005*

*Bernard L. Edwards
Chief Engineer, Microwave and Communication Systems Branch
NASA Goddard Space Flight Center*



Why Optical Communications?

NRC report *Space Technology for the New Century* (1998)

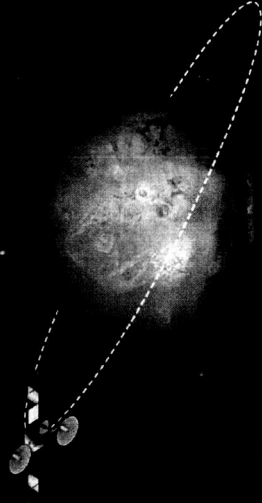
Increased data return from missions to "enable live transmissions of high-resolution images from robotic rovers, orbiters, and astronauts on missions to other planets"

SPACE TECHNOLOGY
FOR THE NEW CENTURY

Space Science Enterprise Strategy (2003)

Optical comm will "enable dramatic improvements in science data rates and will lower the cost per byte of data returned"

SPACE
SCIENCE
ENTERPRISE
STRATEGY



Why Now?

Potential for

- Lower mass and smaller volume components

- Higher gains for given aperture size (less power)

- Higher data rates and/or more efficient systems

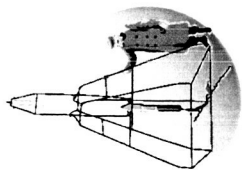
Technology maturity:

- Leverage the Terrestrial Fiber Telecommunications Industry

- Leverage investments made by the Department of Defense



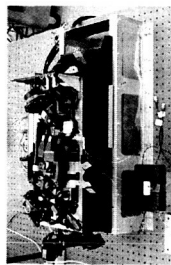
GODDARD SPACE FLIGHT CENTER



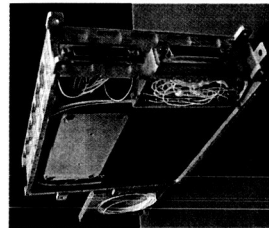
GeOLITE High-Rate, Space-Based Lasercom

Lincoln Laboratory
Provided an Optical Communications
Package for the Department of Defense
which Successfully Demonstrated:

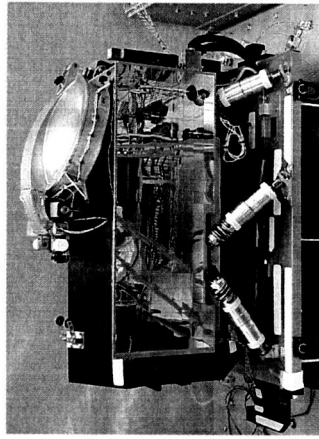
- Up and down lasercom, including space-to-ground and space-to-aircraft
- Robust solution to the challenging problem of stabilizing very narrow beams
- Suitability of many commercial telecommunication components for space



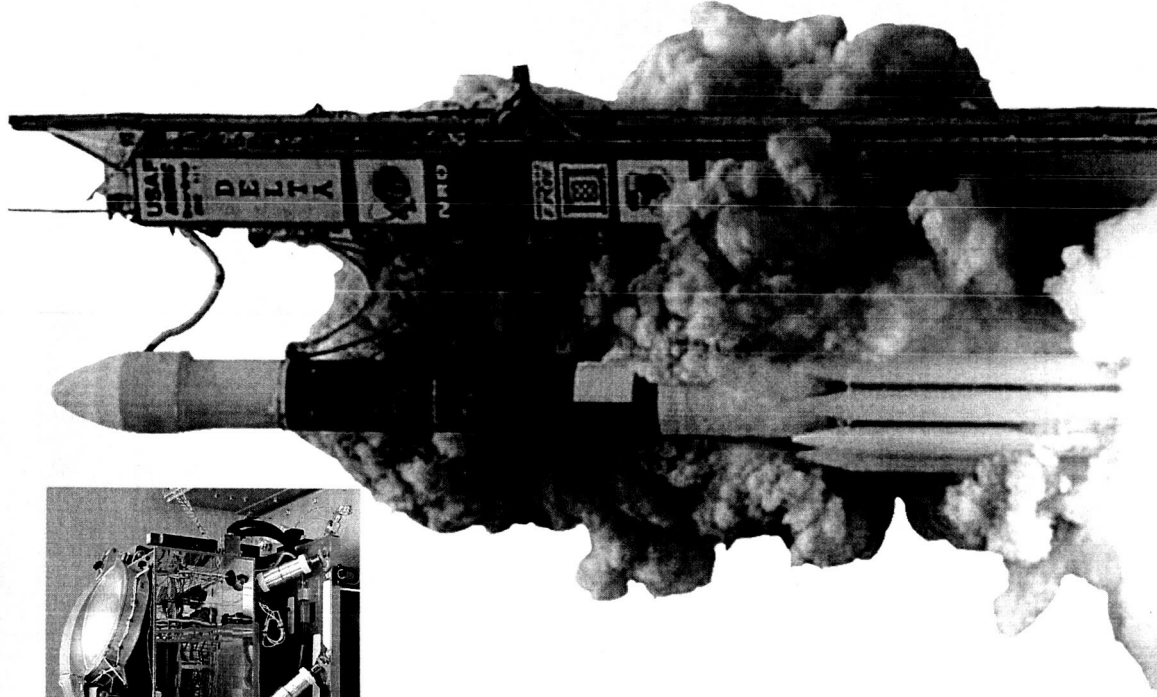
Small Free-Space
Optics

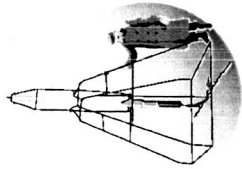


Pump and Beacon
Laser Module



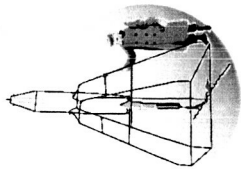
Optical Module



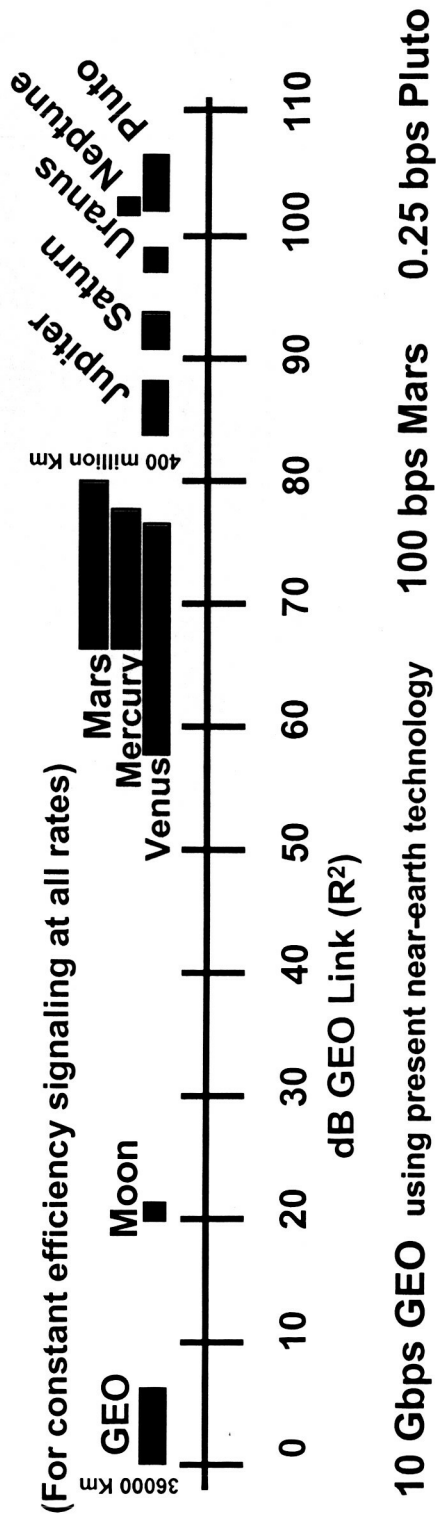


Near Earth vs. Deep Space

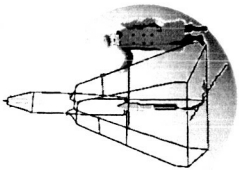
- NASA's optical communication needs could be divided into two areas:
 - Near-Earth
 - Includes Lunar Exploration
 - Deep Space
- There is a significant difference in technology suitable for Near-Earth vs. Deep Space optical communications:
 - Aperture sizes
 - Modulation
 - Wavelength (with Today's technology)
 - Coding
 - Pointing, Acquisition, and Tracking
 - Etc.



Why is Deep Space Different than Near Earth?

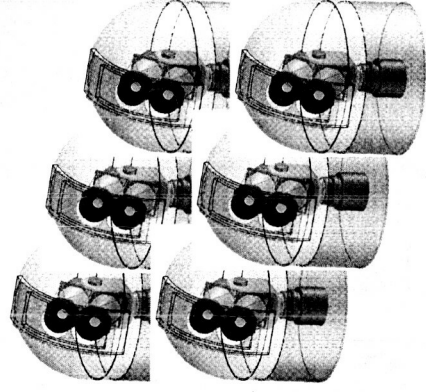
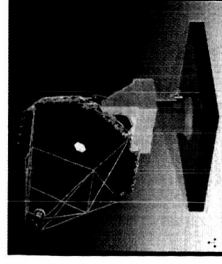


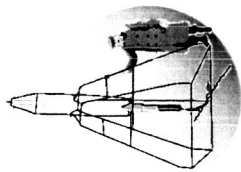
Need 40 dB !



Large Collection Area Needed for Deep Space

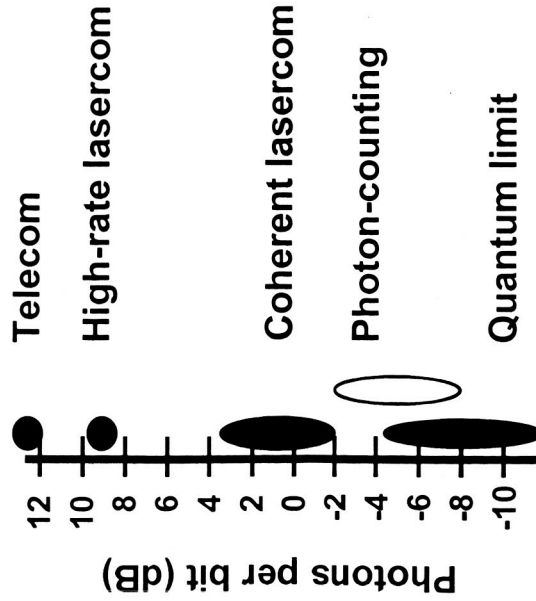
- Large *diffraction-limited* telescope
 - Large collection area
 - Very narrow spatial discrimination/filtering ($\sim \lambda/D$ radians)
 - However -spatial filtering in turbulence is set by r_0 ($\sim \lambda/r_0$)
 - Could be orders of magnitude worse than diffraction-limited
- “Photon bucket” – large, non-diffraction-limited telescope can be constructed of lower quality mirrors, mirror segments, etc
 - Large collection area
 - Same spatial filtering as large aperture when in turbulence
 - Lower cost than diff-ltd
- Array of small telescopes
 - Large collection area
 - Same spatial filtering as large aperture when in turbulence
- Benefits/Costs of a Single Large Aperture
 - Capable dome
 - Possibility for more complex single detector
- Benefits/Costs of an Array of Small Apertures
 - Scalable but many components
 - Requires especially low noise detectors
 - Simpler to achieve small Sun-Earth-Probe angles
 - Concept scales to space-based, mobile





Efficient Signaling and Coding Needed for Deep Space

Lasercom Efficiencies



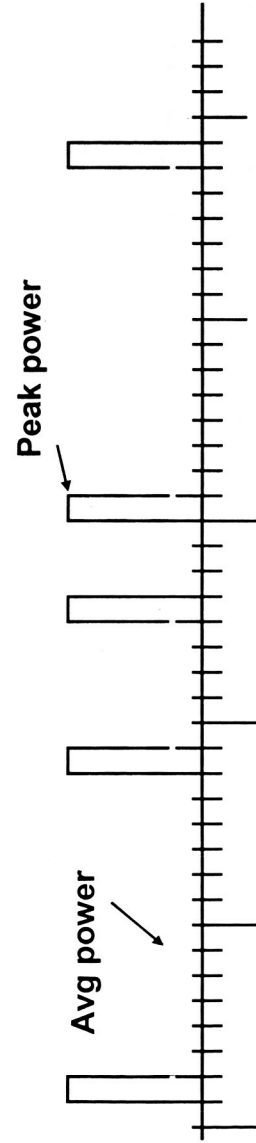
Very near quantum limit

Does not require extreme spectral or spatial purity

Well-matched to pulsed modulation (high peaks pwrs)

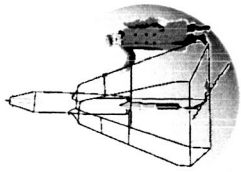
Note: -7 dB photons per bit = 5 BITS PER PHOTON!

Example: 8-ary Pulse Position Modulation



Pulse in one of $8 = 2^3$ slots (3 bits)

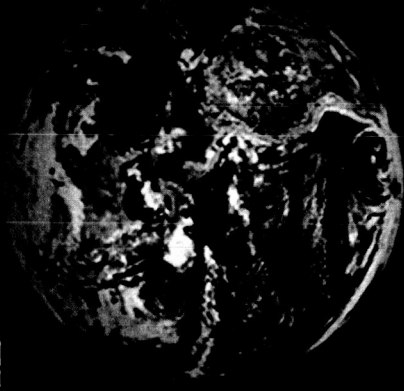
Very powerful Error-Correction
Coding and Decoding implicitly
deduces when a pulse is
missed or when noise fills in
incorrect pulses



Earth Terminal Options

- Ground-based
 - Atmospheric channel effects
 - Reflected background sunlight
 - Turbulence
 - Weather and clouds can block channel
- Airborne
 - Atmospheric channel effects
 - Considerably less reflected background sunlight
 - No turbulence
 - Above weather and clouds
- Space-based
 - No atmospheric channel or weather effects

Key Parameters of a Typical Lunar Lasercom System



Transmitter at the Moon

30 cm Aperture

5 W Fiber Amplifier

1.55 μm

Differential Phase Shift Keying Modulation with
conventional FEC

Receiver at Earth on the Ground

30 cm to 1 Meter Aperture

Supports ~ 500 Mbits/second to 1 Gbits/second

Receiver at Earth in Space

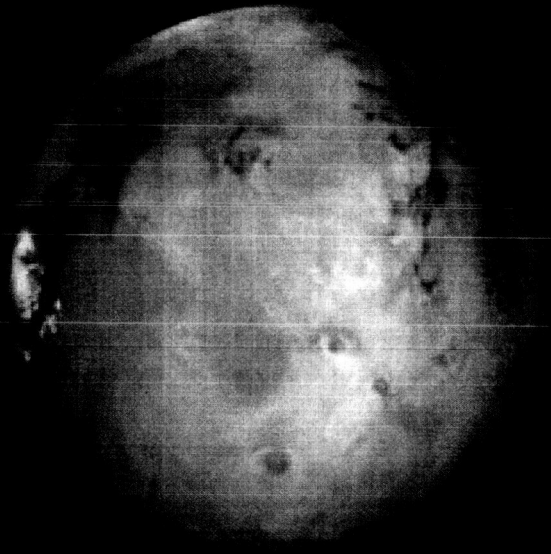
30 cm Aperture

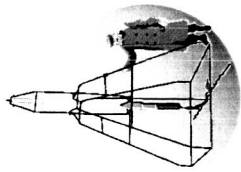
Supports ~1 to 2.5 Gbits/second



Key Parameters of a Typical Mars Lasercom System

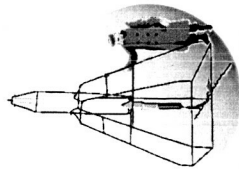
- Transmitter at Mars
 - 30 cm Aperture
 - 5 W Fiber Amplifier
 - 1.06 μm
 - Pulsed Position Modulation with Concatenated Codes
- Receiver at Earth on the Ground
 - 2.5 to 5 Meter Class Aperture
 - Single Large or an Array of Small Telescopes
 - Supports 1 - 50 Mbits/second depending on range
- Receiver at Earth in Space
 - 2 Meter Class Aperture
 - Single Large or an Array of Small Telescopes
 - Supports 1 - 50 Mbits/second depending on range





Future Optical Backbone Network

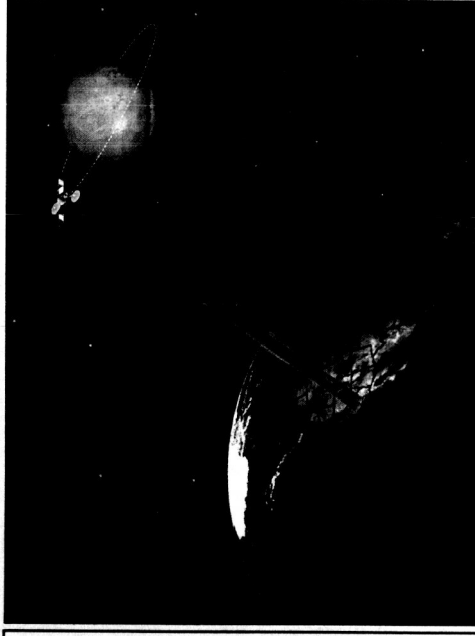
- Lunar Exploration
 - Provide Gbits/second to and from the moon.
 - Would incorporate "Near-Earth Class" lasercom terminals
 - GeoLITE-like
 - Leverage Department of Defense investments.
- Mars and Beyond Exploration
 - Provide 10's to 100's of Mbits/second from Mars.
 - As photon counting technology improves, this will increase
 - Space-based Earth terminals can support high speed forward links to Mars
 - Would incorporate "Deep Space Class" lasercom terminals
 - Photon-starved optical channel
 - NASA's Science Mission Directorate is funding the \$300 million Mars Laser Communication Demonstration as a pathfinder.



Overview of the Mars Laser Communication Demonstration

MLCD Important Features

- Demonstrate deep-space Optical Communications from Mars.
- Project Management by NASA's Goddard Space Flight Center, Flight Terminal implemented by MIT Lincoln Laboratory, and Ground Terminal managed by NASA's Jet Propulsion Laboratory.
- Flight Terminal will be a payload on the Mars Telecommunications Orbiter spacecraft.
- Launch Date: October 2009
- Demonstration Lifetime Period: ~ 3 Years



Mars Terminal

- Generate Optical Power
- Encode and Modulate the Data between .1 and 50 Mbps
- Point and stabilize outgoing beam through a Hybrid inertial / beacon / Earth tracking concept.
- Receive uplink commands at approximately 10 bps

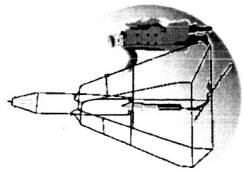
Earth Terminal

- Use a large effective aperture area to collect enough light to overcome the extreme range.
- Couple the captured light onto efficient detection hardware.
- Demodulate and decode the signal.
- Transmit a beacon and uplink commands.
- Needs to operate in daylight

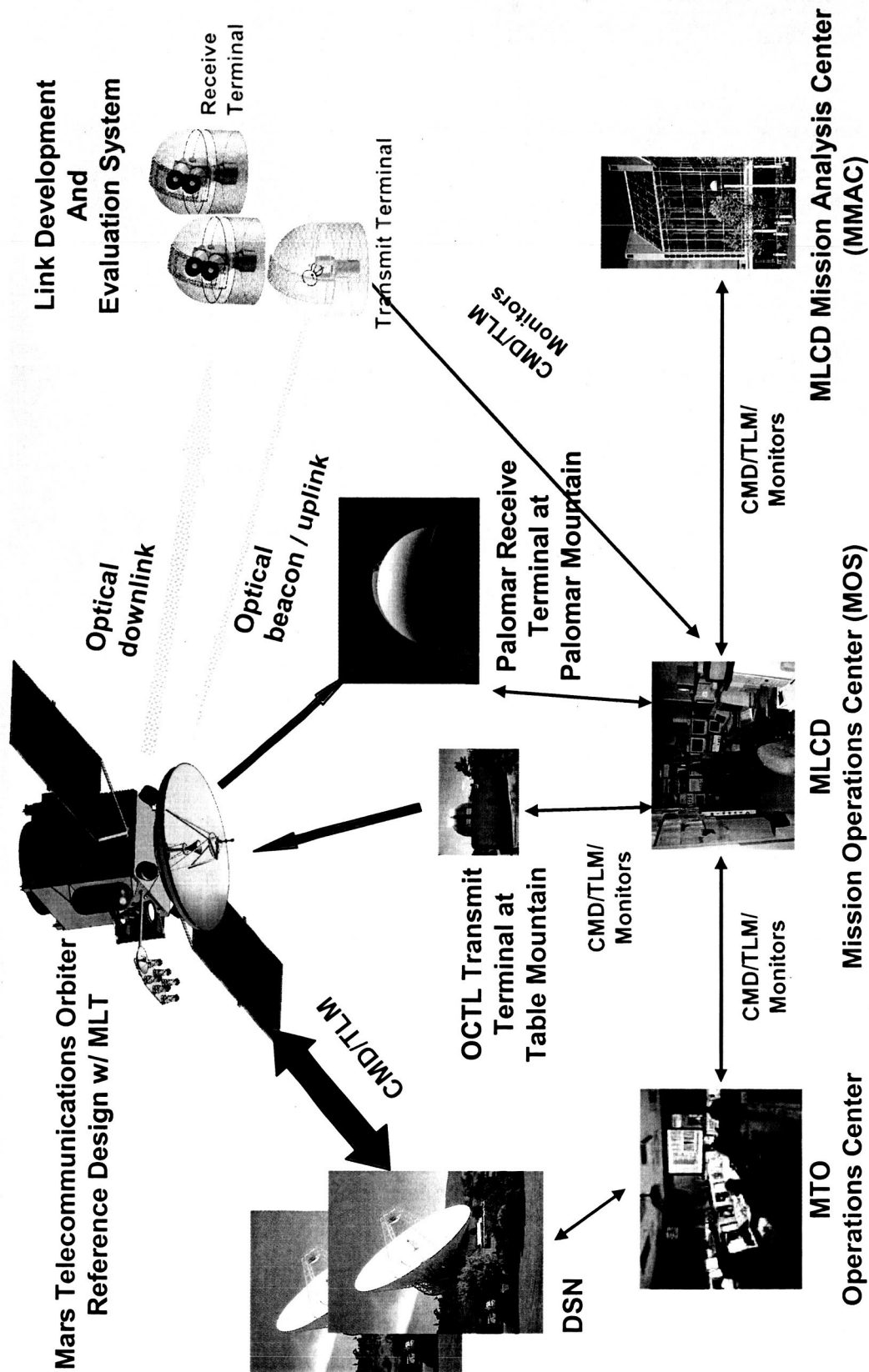
Link Control

- Dynamically select terrestrial site and inform Mars terminal
- Optimize lasercom parameters for changing conditions and inform all terminals
- Coordinate transmission, buffers, retransmissions, ...

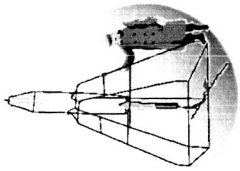




MLCD System Block Diagram

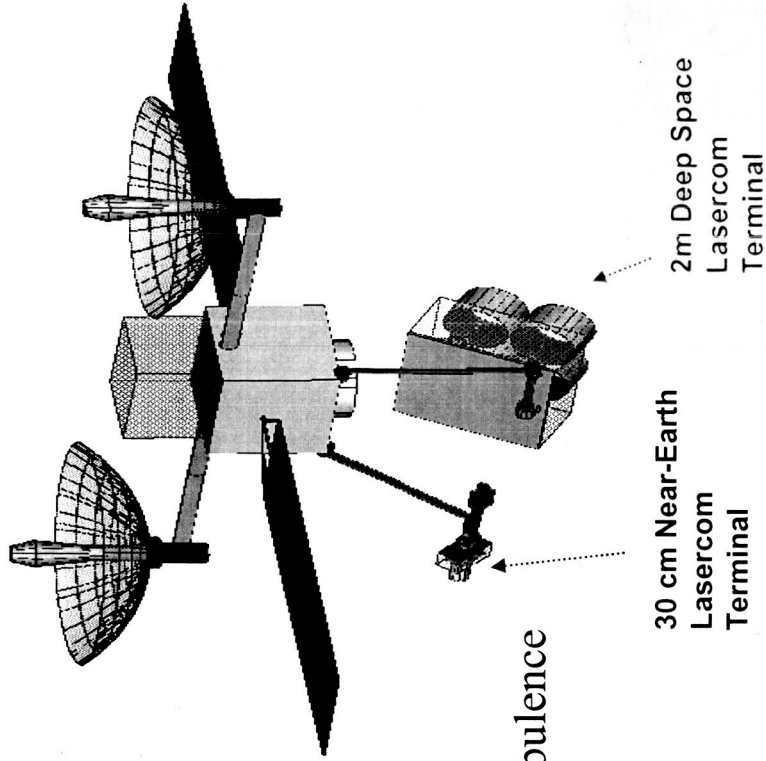


Operations Center
GODDARD SPACE FLIGHT CENTER



A Possibility: Integrated Near Earth and Deep Space Lasercom Spacecraft

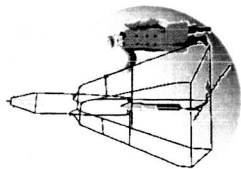
An integrated spacecraft can be flown to support NASA's RF, near-Earth, and Deep Space Optical Communications needs



- **Benefits of Space-Based Optical Receivers Include:**

- ✓ Good Visibility to Deep Space
 - One GEO provides ~ 90% visibility
 - Two GEOs provide 100%
- ✓ Not susceptible to weather and atmospheric/turbulence
 - Easy concept of operations
 - Fewer handovers to perform
 - Can receive streaming data without losses
- ✓ Simplified Uplink Beacon
 - Eliminates issues related to safety and avoidance
 - High power can be used for high rate commanding / forward link

- **An Integrated Spacecraft could facilitate data distribution.**



Summary

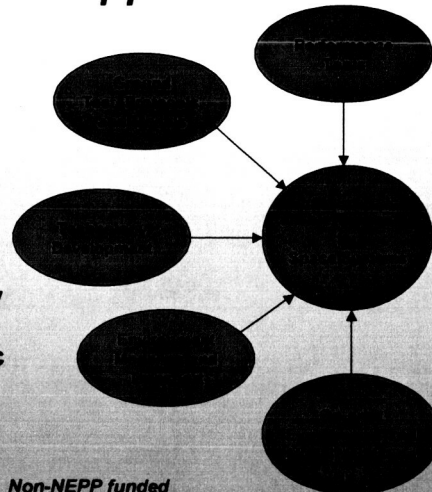
- Optical communications can provide high speed communications throughout the solar system
 - Enable new science missions and Human exploration
- The technology suitable for Near-Earth optical communications, including communications to and from the Moon, is different than for Deep Space optical communications.
 - NASA could leverage DoD investments for Near-Earth applications, including the Moon.
 - NASA will have to develop its own technology for Deep Space. The Mars Laser Communication Demonstration is a pathfinder.
- NASA's Science Mission Directorate, under the leadership of Dr. Barry Goldzahler, is developing a roadmap for the development of deep space optical communications



Insertion of New Technologies *The Big Picture Approach*



- Develop knowledge-base of existing technology information
- Determine reliability/radiation gaps
- Perform ground-based tests where appropriate
 - May be sufficient to “qualify” for a specific mission, but not generically for all
- Develop technology-specific models/test protocols
 - Performance Predictions
- Validate models with flight data
 - Requires in-situ environment monitoring



Non-NEPP funded
flight hardware

"Risk Management of Microelectronics: NEPP Program" presented by Kenneth A. LaBel, GOMAC 2005, Las Vegas, NV, April 6, 2005

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